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Measurement of the $|V_{ub}|$ matrix element at LEP

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OUTLINE:

- Physics motivations
- Method used at LEP to measure $\mathrm{BR}(\mathrm{b} \to \mathrm{X_u}\ell\nu)$
- ALEPH result
- L3 result
- DELPHI result
- Combination of the three LEP experiments
- Conclusion

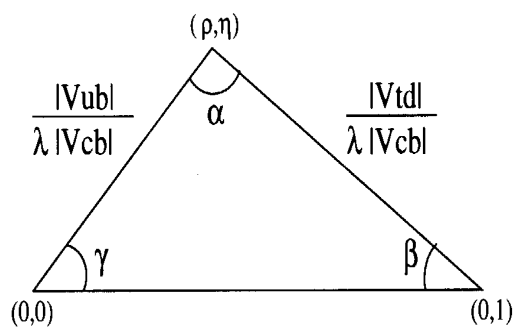
Physics motivations

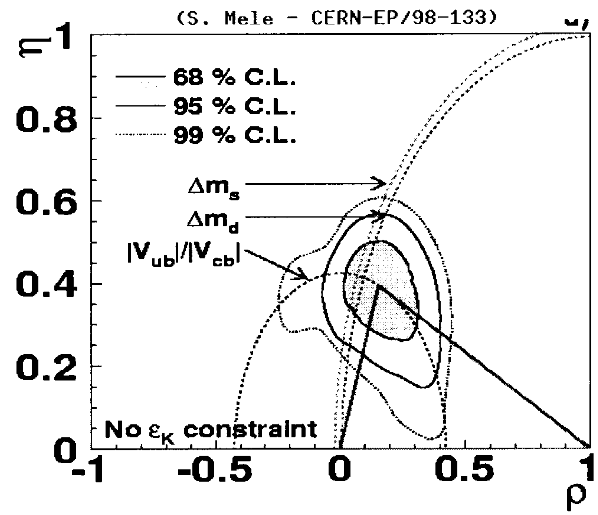
Mixing of quarks in the charged weak interaction is described by the Cabibbo-Kobayashi-Maskawa matrix:

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$= \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

$V^\dagger V = 1$ gives unitarity relations $(\mathrm{V_{ud}V^\star_{ub}} + \mathrm{V_{cd}V^\star_{cb}} + \mathrm{V_{td}V^\star_{tb}})$ which can be visualised by a triangle in the (ρ, η) plane (Unitarity triangle).





In the framework of the CKM matrix, the magnitude of the CP violation phenomena is related to the area of the Unitarity triangle.

$\Rightarrow$ Tests of the SM predictions for CP violation requires a detailed study of the triangle: sides and angles.

$\Downarrow$

A precise measurement of $|V_{ub}|$ is needed

How to do that ?

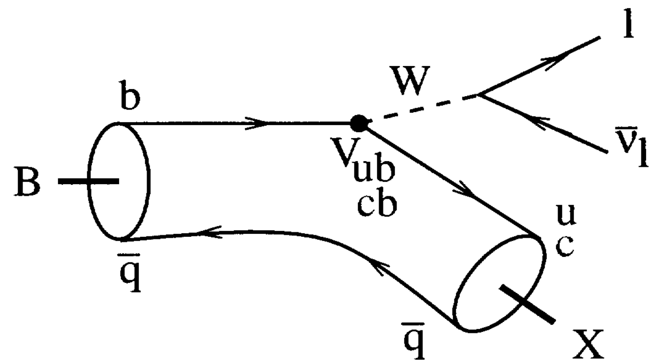
Process	Branching ratio	Experimental point of view	Theoretical point of view
Purely hadronic $\mathrm{B} \to \pi\pi,\ \mathrm{K}\pi,\ \ldots$	$10^{-4} - 10^{-5}$	"Easy" with a good vertexing	Large uncertainties
Purely leptonic $\mathrm{B} \to \ell\nu_\ell$	$10^{-5} - 10^{-12}$	Very difficult and large statistics needed	Accurate predictions
Exclusive semileptonic $\mathrm{B} \to \pi(\rho)\ell\nu$	$\simeq 10^{-4}$	Need to reconstruct the lepton and one resonance	Problem with Form factors
Inclusive semileptonic $\mathrm{b} \to \mathrm{X_u}\ell\nu$	$\simeq 10^{-3}$	Need to reconstruct **all** the particles in the final state	Accurate predictions $\Delta\lvert\mathrm{V_{ub}}\rvert/\lvert\mathrm{V_{ub}}\rvert \simeq 4\%$

$$\Downarrow$$

Use Inclusive semileptonic b decays

Semileptonic b decays

$\mathrm{b} \rightarrow \mathrm{c}$ transitions ($\propto |\mathrm{V_{cb}}|^2$) are dominant with respect to the $\mathrm{b} \rightarrow \mathrm{u}$ transitions ($\propto |\mathrm{V_{ub}}|^2$).



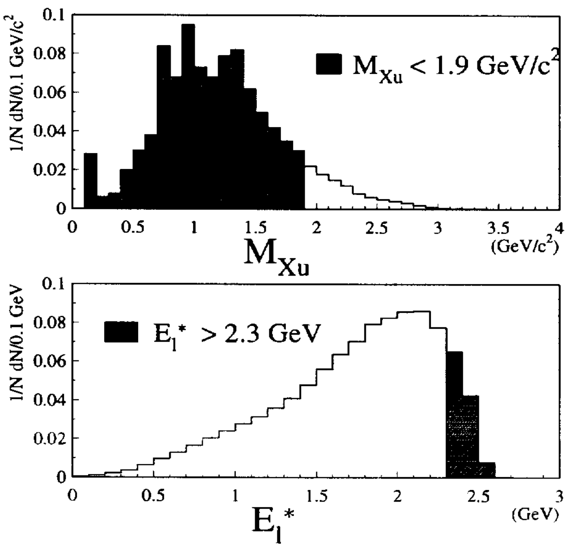
with $\begin{cases} X_c = D - D^* - D^{**} - D^{(*)}\pi \\ X_u = \pi - \eta^{(\prime)} - \rho - \omega - \ldots - \pi\pi - \pi\pi\pi - \ldots \end{cases}$

Two approaches can be used to extract the value of $|\mathrm{V_{ub}}|$ from this process:

- Use **only** the charged lepton and restrict the study to the **end point** of the lepton momentum distribution. (above the charm kinematic threshold). $\rightarrow$ Method used by CLEO and ARGUS.
- Use **all** the particles of the final state (lepton, neutrino and hadronic system X) to reduce the model dependence. $\rightarrow$ Method used for the first time at LEP by ALEPH, DELPHI and L3.

Experimental situation

The $\mathrm{b} \to \mathrm{X_u} \ell \nu$ transitions are characterised by a low $\mathrm{M_X}$ spectrum and a high lepton energy E_ℓ^* end-point:

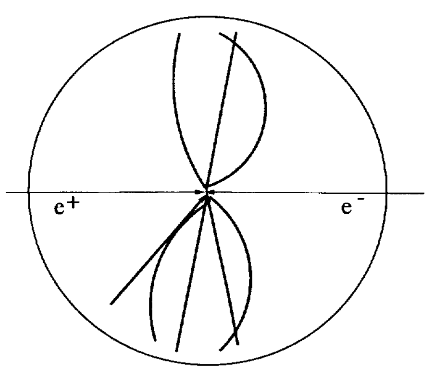


$\epsilon_{\mathrm{b}\to\mathrm{u}} \approx 90\,\%$
for $\mathrm{M_X} < 1.87\ \mathrm{GeV/c^2}$

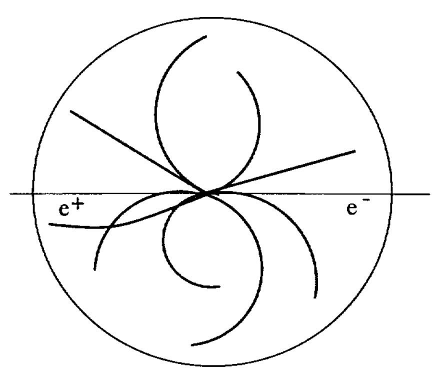
$\epsilon_{\mathrm{b}\to\mathrm{u}} \approx 10\,\%$
for $\mathrm{E}_\ell^* > 2.31\ \mathrm{GeV}$

CLEO	$\longrightarrow$	two B produced almost at rest
	$\Rightarrow$	decay products completely mixed
LEP experiments	$\longrightarrow$	b quarks boosted
$(4 \times 10^6\ Z \to b\bar{b})$	$\Rightarrow$	B decay products well separated

LEP



CLEO



Strategy used to measure $\mathrm{BR}(b \to X_u \ell \nu)$ at LEP

Inclusive reconstruction of the
$b \to X \ell \nu$ final state
$\Rightarrow$ reject tracks from fragmentation

$\Downarrow$

Discriminate $b \to X_u \ell \nu$ from $b \to c + \text{lepton}$
$\Rightarrow$ use kinematic variables (p_ℓ, p_ν, M_X, ...)
plus vertexing and Kaon Id (DELPHI)

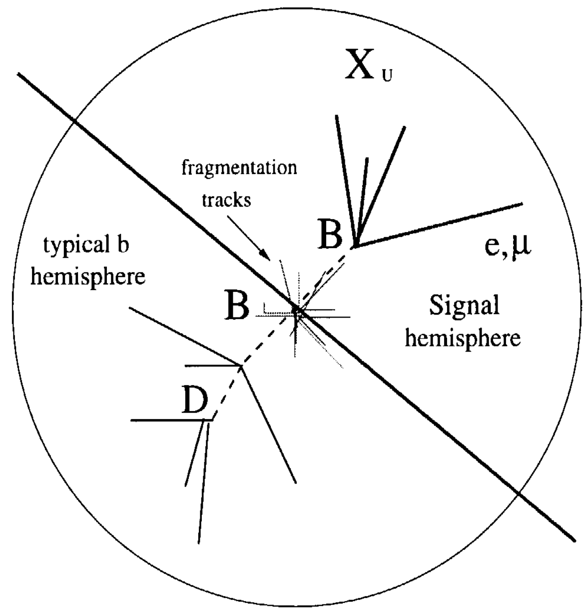
$\Downarrow$

Measure $\mathrm{BR}(b \to X_u \ell \nu)$
$\Rightarrow$ systematics and checks

$\Downarrow$

Extract the value of $|V_{ub}|$

A "Typical" signal
LEP event



$\Downarrow$

Select events with a lepton &
b-tag the opposite hemisphere
$\rightarrow$ Pure $Z \rightarrow b\bar{b}$ sample

ALEPH analysis: Inclusive reconstruction of $b \to X\ell\nu$ decays

(First presentation at the EPS Conference of Warsaw in 1996 – Published in Euro. Phys. Jour. C6 (1999) 555-574)

- Select a **lepton** (e or μ) with $p > 3$ GeV/c
- Reconstruct the **neutrino** as the missing momentum of the event.
- Select the tracks (charged and neutral) of the **hadronic system** ($\sim$ 4-5). Need to reject tracks from fragmentation ($\sim$ 7-8).

$\rightarrow$ use the kinematic properties of the tracks (momentum, angle with the lepton, rapidity, ...) and the impact parameter information

$\Downarrow$

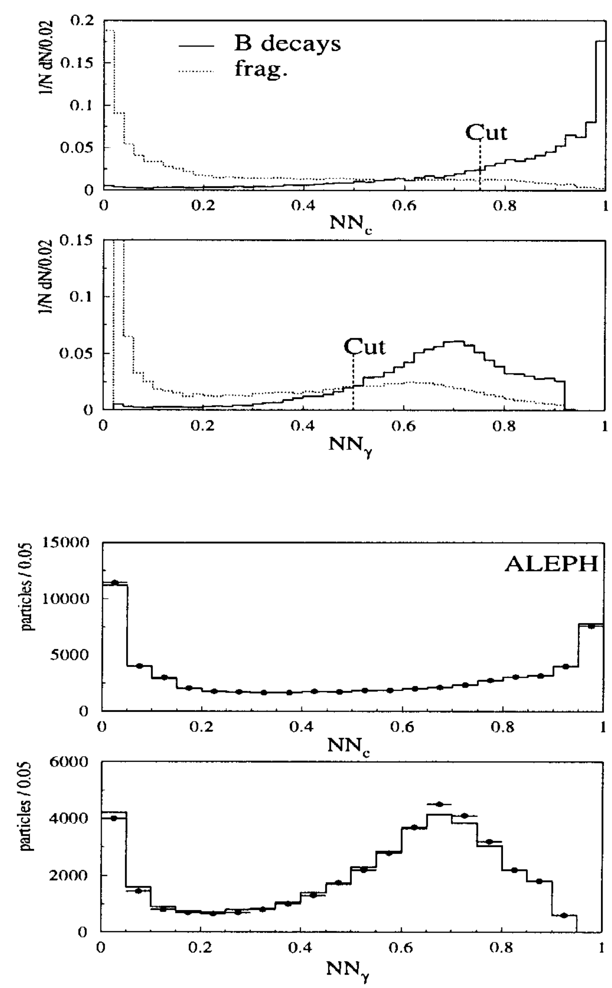
Use these variables as input of two Neural Networks: NN_c to select charged tracks and NN_γ to select photons.

$\Downarrow$

Efficiency: 85% & Purity: 80%

$< \Delta\theta_B > \sim 70$ mrad

$\sigma(p_B) \sim 4$ GeV/c



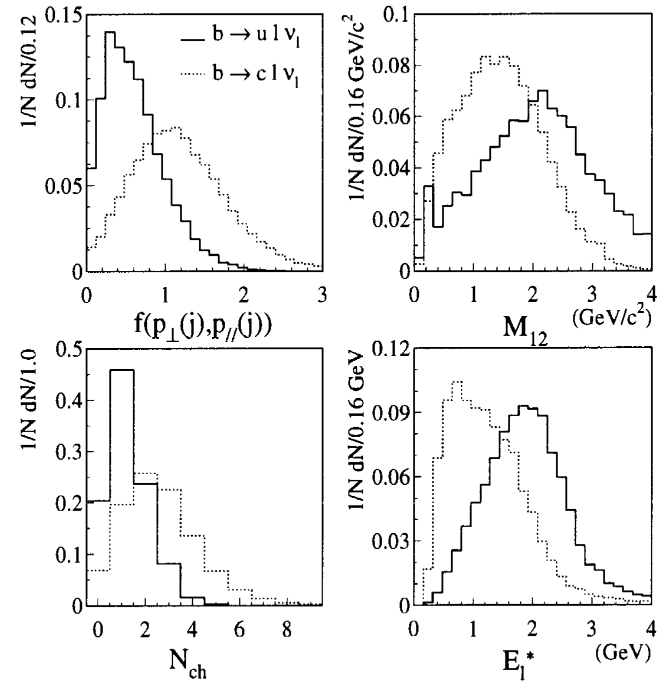
ALEPH analysis: Discrimination between $b \to X\ell\nu$ and $b \to c +$ lepton

Discrimination based on the fact that the c quark is heavy compared to the u quark $\Rightarrow$ Different **kinematic** properties for the two final states such as Sphericity, track multiplicities, energy, invariant masses, momenta and transverse momenta of the particles, ...

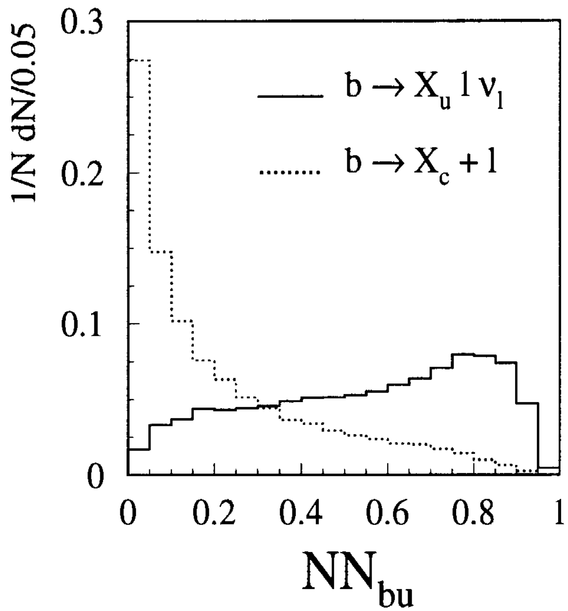
$\Downarrow$

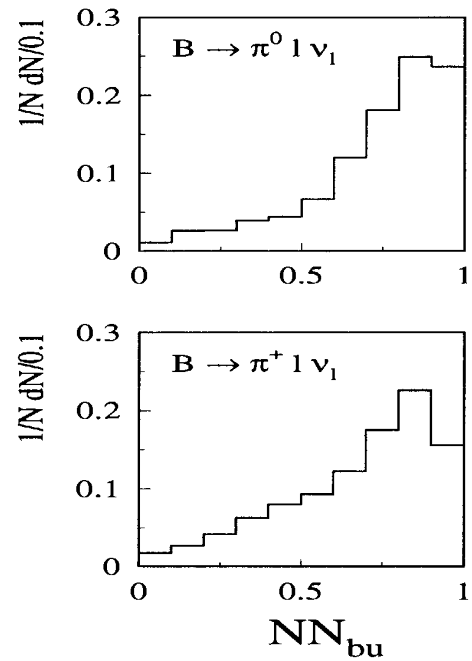
Use the **lepton**, the **neutrino** and the **hadronic system** X to build the variables and combine them in a Neural Network $\mathrm{NN_{bu}}$ with the following constraints:

- A good discrimination between $b \to X_u\ell\nu$ and $b \to X_c\ell\nu$.
- A reduced sensitivity to the compo sition of the hadronic system X.



ALEPH analysis: Discrimination between $b \rightarrow X\ell\nu$ and $b \rightarrow c +$ lepton

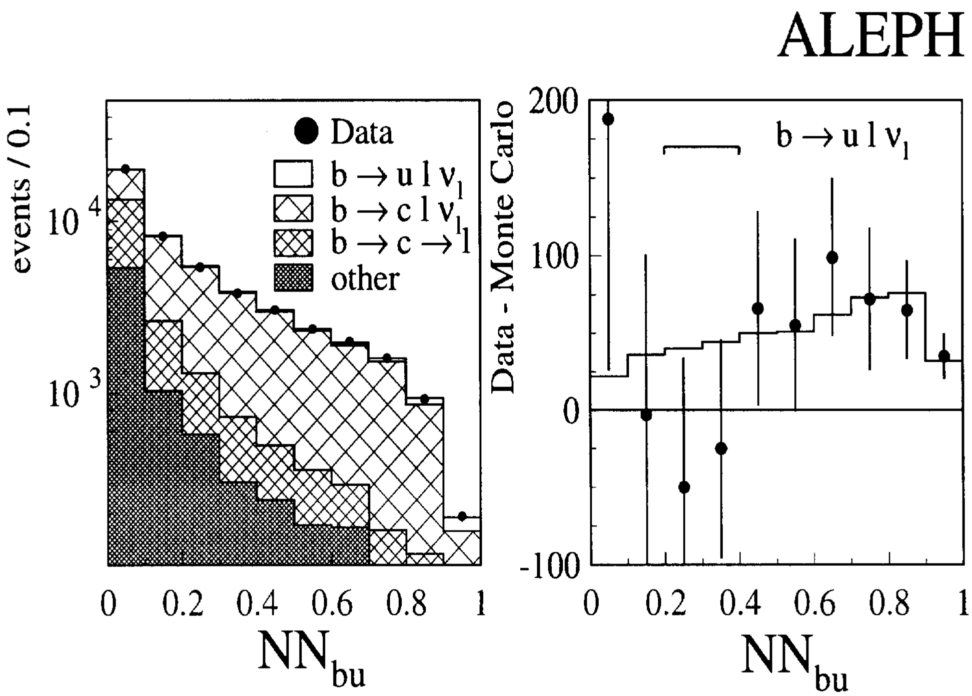




$\Downarrow$

Neural Network output similar for charged and purely neutral X_u final states
$\rightarrow$ Reduced systematic errors.

ALEPH result on $\mathrm{Br}(b \to X_u \ell \nu)$



Fit of $\mathrm{NN_{bu}}$ between 0.6 and 1.0 $\Longrightarrow \epsilon_{b \to X_u l \nu_l} = 50\,\%$

$\longrightarrow$ excess of events (303 ± 88):

$$\mathrm{Br}(b \to X_u \ell \nu) = (1.73 \quad \pm 0.55_{stat} \pm 0.51_{syst\, b \to c} \pm 0.21_{syst\, b \to u}) \times 10^{-3}$$

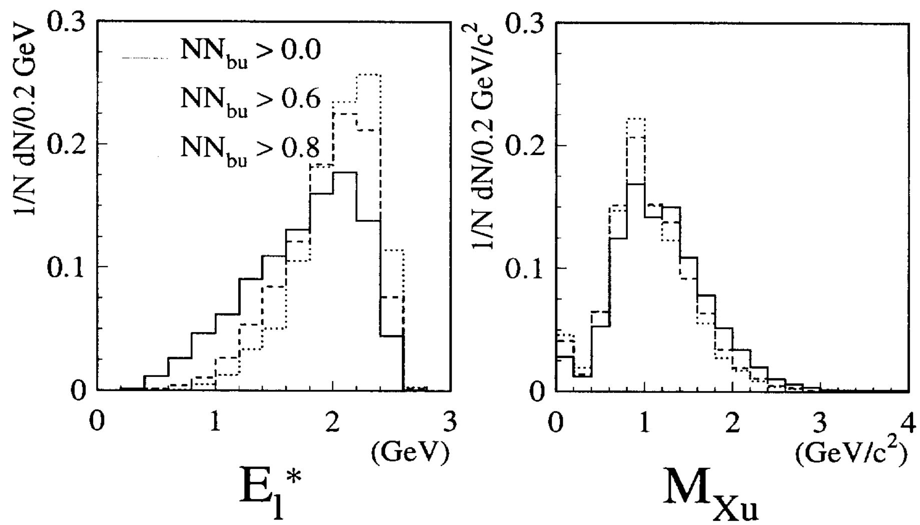
Background error	$\Delta\mathrm{Br}(b \to X_u \ell \nu)$
b-hadron production	$\pm 0.16 \times 10^{-3}$
b-hadron decay	$\pm 0.31 \times 10^{-3}$
c-hadron decay	$\pm 0.37 \times 10^{-3}$
lepton identification	$\pm 0.08 \times 10^{-3}$

ALEPH result: modelling of the $b \to X_u \ell \nu$ transitions

Use the Hybrid model of Ramirez et al. (C. Ramirez, J. F. Donoghue and G. Burdman, Phys. Rev. **D41**(1990) 1496.) to describe the $b \to X_u \ell \nu$ transitions:

$$\begin{cases} E_u^* < 1.6\,\mathrm{GeV} \longrightarrow \text{resonant states (25 \%) with ISGW2} \\ E_u^* > 1.6\,\mathrm{GeV} \longrightarrow \text{multi-pions states (75 \%) with DSU} \end{cases}$$

DSU: (R. D. Dikeman, M. Shifman and N. G. Uraltsev, Int. Jour. Mod. Phys. **A11** (1996) 571; R. D. Dikeman and N. G. Uraltsev, Nucl. Phys. **B 509** (1998) 378.)



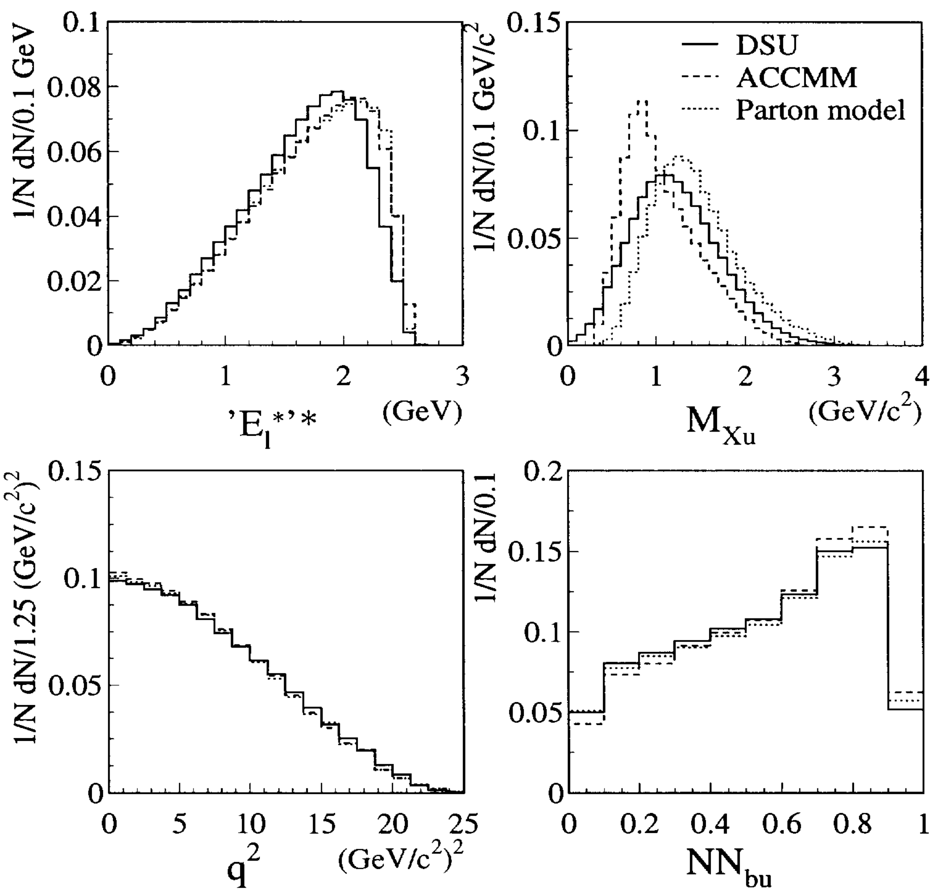
$\Downarrow$

Small bias introduced by the cut on $\mathrm{NN_{bu}}$

Signal error	$\Delta \mathrm{Br}(b \to X_u \ell \nu)$
Hybrid model parameter	$\pm 0.08 \times 10^{-3}$
Exclusive model	$\pm 0.05 \times 10^{-3}$
Inclusive model	$\pm 0.18 \times 10^{-3}$
Λ_b modelling	$\pm 0.04 \times 10^{-3}$

ALEPH result: modelling of the $b \to X_u \ell \nu$ transitions

Models used for non-resonant final states in $b \to X_u \ell \nu$ transitions:



- DSU: R. D. Dikeman, M. Shifman and N. G. Uraltsev, Int. Jour. Mod. Phys. **A11** (1996) 571; R. D. Dikeman and N. G. Uraltsev, Nucl. Phys. **B 509** (1998) 378.
- ACCMM: G. Altarelli *et al.*, Nucl. Phys. **B208** (1982) 365; G. Altarelli and S. Petrarca, Phys. Lett. **B261** (1991) 303.
- Parton model: A. Bareiss and E. A. Paschos, Nucl. Phys. **B327** (1989) 353; C. H. Jin, W. F. Palmer and E. A. Paschos, Phys. Lett. **B329** (1994) 384; K. Y. Lee and J. K. Kim, Phys. Lett. **B379** (1996) 202.

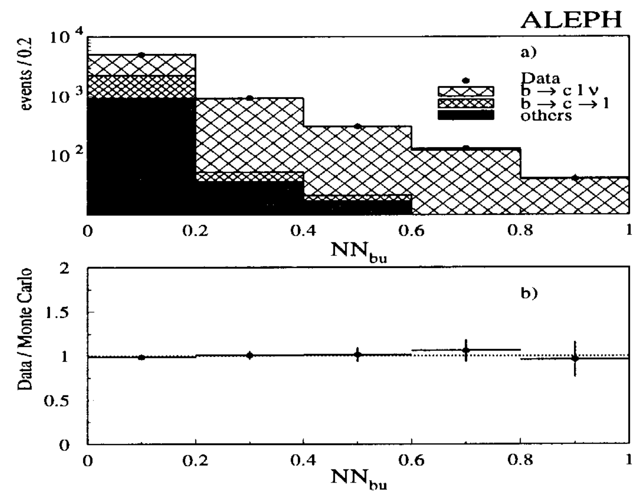
ALEPH result: Systematics - Full table

Source	Variation	ΔBr (10^{-3})
Photons from fragmentation	$\pm 10\%$	∓ 0.12
Boost of the b hadron	—	± 0.07
B_s production rate	$(11.2 \pm 1.9)\%$	∓ 0.01
Λ_b production rate	$(11.3 \pm 2.3)\%$	∓ 0.07
Λ_b polarization	$(-30 \pm 30)\%$	∓ 0.01
$\epsilon_c^{\mathrm{lifetime}}$	$\pm 13\%$	± 0.02
$\sigma_{\mathrm{stat}}^{b \to c}$	—	± 0.22
$b \to \ell$ modelling	28% of D^{**} 8% of D^{**}	$^{+0.06}_{-0.16}$
$D^{**}/(D^*\pi)$	1.0 ± 0.5	$^{-0.03}_{+0.05}$
4-body rate in Λ_b SL decays	$(20 \pm 20)\%$	± 0.12
$B \to D$ modelling	—	∓ 0.04
$c \to \ell$ modelling	—	± 0.14
$Br(b \to \psi \to \ell)$	$\pm 14\%$	∓ 0.01
$Br(b \to \tau \to \ell)$	$\pm 18\%$	± 0.00
$Br(b \to \bar{c} \to \ell)$	$\pm 50\%$	± 0.00
c hadron topological B.R.	—	± 0.34
no. of neutrals in c decays	—	± 0.11
$D \to K_L^0 X$	—	± 0.08
D^0/D^+	2.59 ± 0.52	∓ 0.04
$\Lambda_c \to nX$	0.50 ± 0.16	∓ 0.07
Electron ID efficiency	$\pm 2\%$	∓ 0.03
Photon conversions	$\pm 10\%$	± 0.00
Electron background	$\pm 10\%$	± 0.00
Muon ID efficiency	$\pm 2\%$	∓ 0.05
Decaying hadrons	$\pm 10\%$	± 0.00
Punch-through	$\pm 20\%$	∓ 0.04
Punch + decays shape		± 0.04
Total $b \to c$ systematic uncertainty		**± 0.51**
Value of the cutoff Λ	0 GeV $\to \infty$	$^{+0.06}_{-0.10}$
Exclusive model	JETSET	± 0.05
Inclusive model	ACCMM Parton model	± 0.18
Λ_b modelling	—	± 0.04
Total $b \to u$ systematic uncertainty		**± 0.21**
Total systematic uncertainty		**± 0.55**

ALEPH checks (Part I)

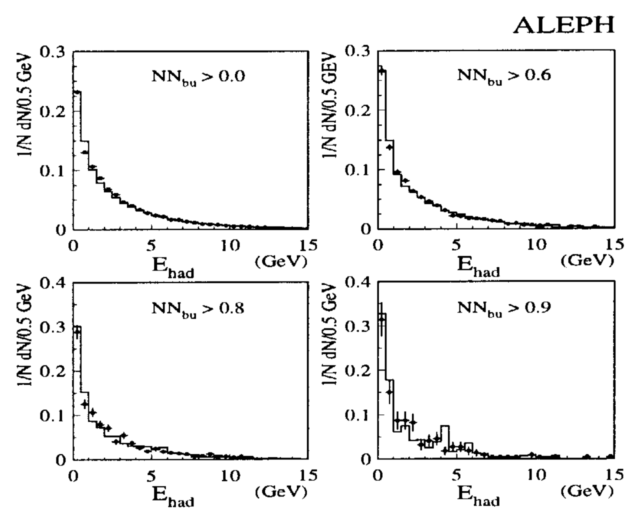
1. $\mathrm{b} \to \mathrm{X_c}\ell\nu$ transitions

Select hemispheres with a **lepton** and a reconstructed **D meson** $\Rightarrow$ Pure $\mathrm{b} \to \mathrm{X_c}\ell\nu$ sample. Good agreement between data and MC in the signal region



2. Neutral hadron production

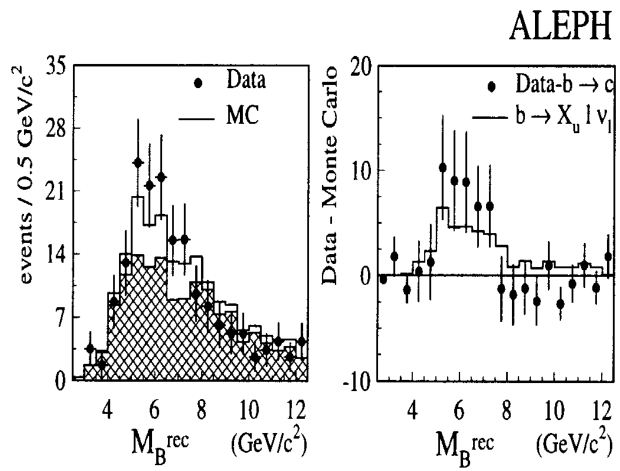
Look at the neutral hadronic energy reconstructed in a 30° cone around the lepton for different cuts on $\mathrm{NN_{bu}}$. Good agreement between data and simulation for all the cuts.
Also measure the inclusive production rate of $\mathrm{K^0_L}$ in D meson decays as a consistency check. The result, $\mathrm{Br(D \to K^0_L X)} = (24.0 \pm 4.4)\%$, is in good agreement with the MARKIII result.



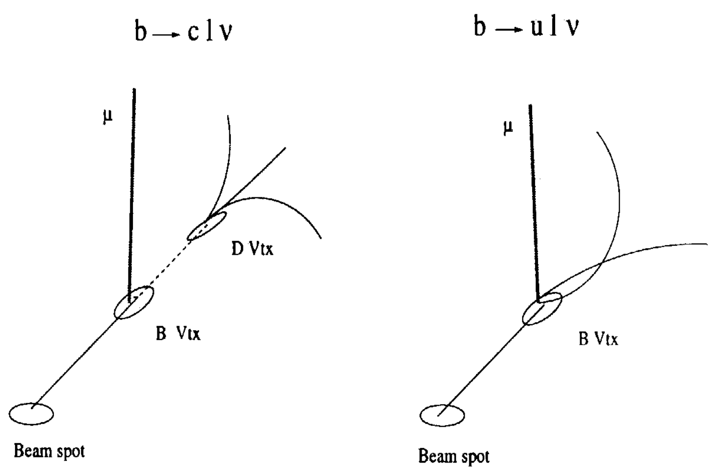
ALEPH checks (Part II)

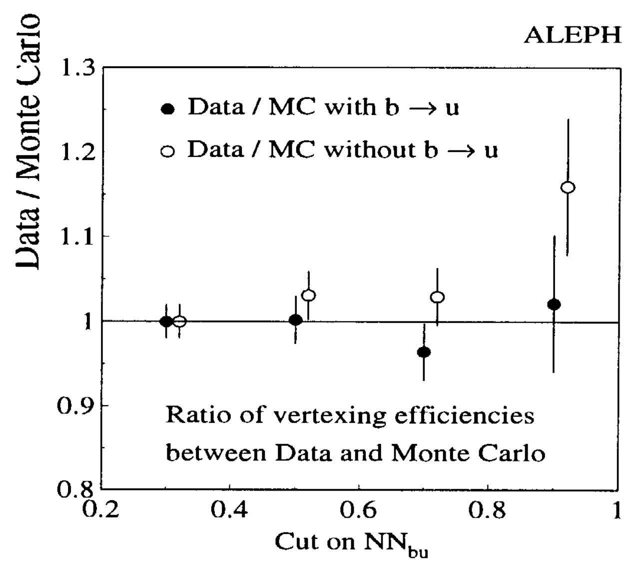
3. Evidence in M_B^{rec} distribution

Look at the invariant mass M_B^{rec} of the $X\ell\nu$ system for $NN_{bu} > 0.9$. Good agreement between data and Monte Carlo except in the region $4 < M_B^{rec} < 8$ GeV/c^2 where an excess of events is seen to be compatible with the measured signal $b \to X_u \ell \nu_\ell$ transitions.



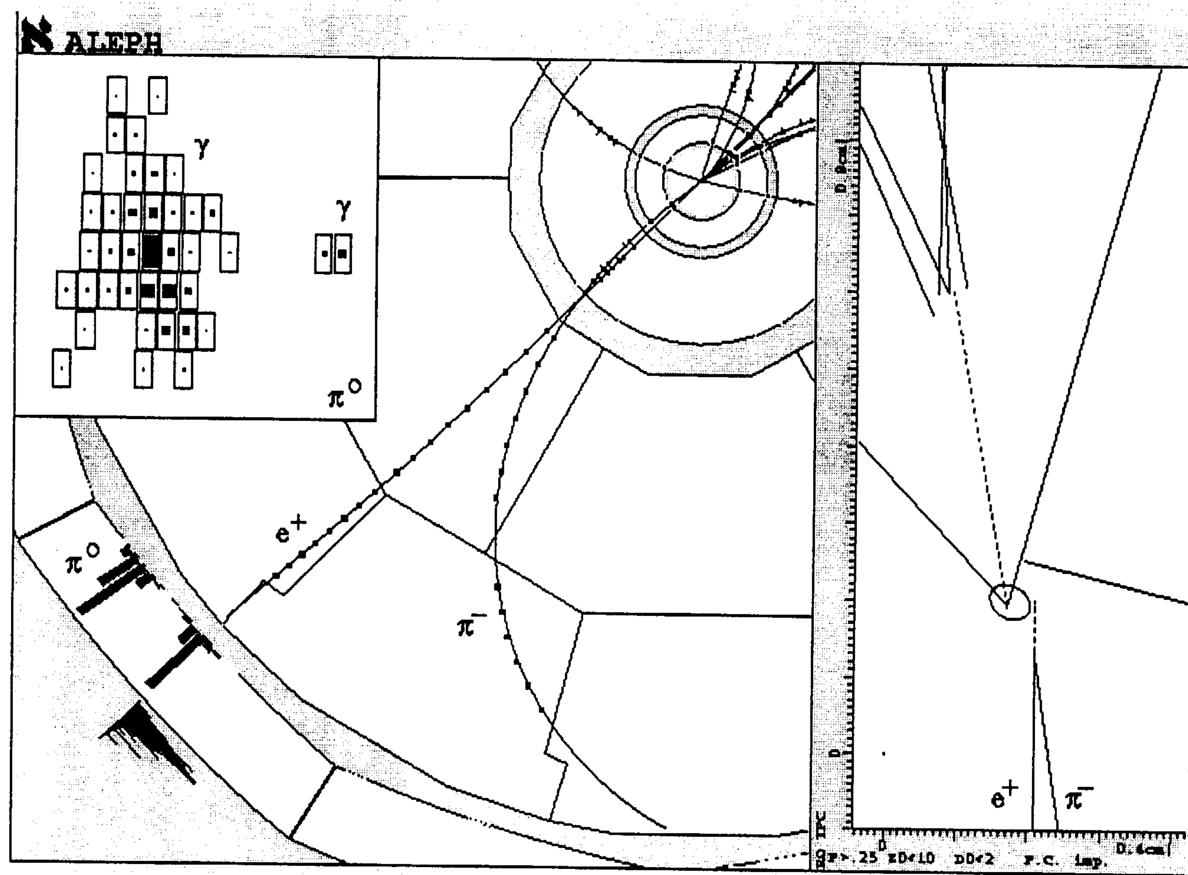
4. Evidence in the vertexing





ALEPH checks (Part III)

For $\mathrm{NN_{bu}} > 0.9$, 35 events (among 192) are expected to come from $\mathrm{b} \to \mathrm{u}$ transitions, of which 3.8 from $\mathrm{X_u} = \pi^-$ or ρ^-. Two such events were found and the $\mathrm{B^0} \to \rho^-\mathrm{e}^+\nu_\mathrm{e}$ candidate event is shown below.

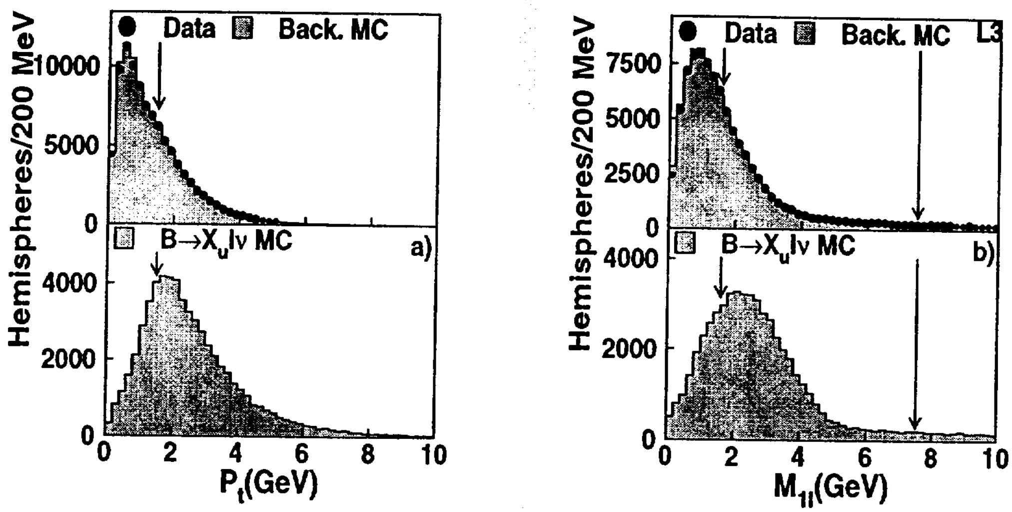


L3 analysis:

(Published in Phys. Lett. B436 (1998) 174-186)

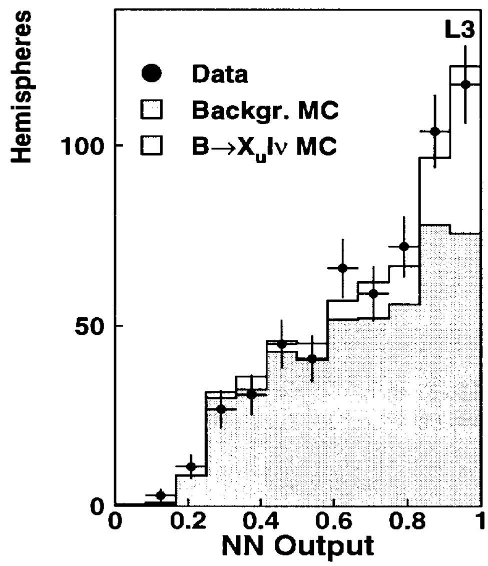
Inclusive reconstruction of $\mathrm{b} \to \mathrm{X_u}\ell\nu$ decays.

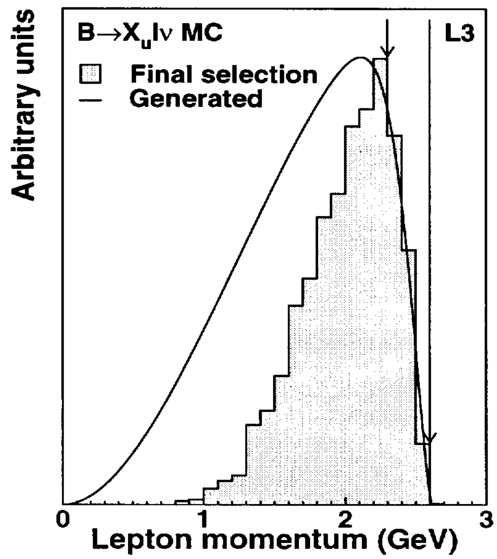
- Select events with an energetic **lepton**.
- Construct eight discriminating variables with the **two most energetic tracks** of the lepton hemisphere ($\mathrm{p}_\perp^\ell$, $\mathrm{m}_{1\ell}$, p_2...).



- Apply cuts on the eight variables $\Longrightarrow \epsilon_{\mathrm{b}\to\mathrm{X_u}\ell\nu} = 1.5\,\%$
- Count the remaining events $\longrightarrow$ excess of 81 events.
- Check done with a neural network (8/14/8/1) combining the eight variables.

L3 result on $\mathrm{Br}(\mathrm{b} \to \mathrm{X_u}\ell\nu)$





$$\mathrm{Br}(\mathrm{b} \to \mathrm{X_u} \mathrm{l} \nu_\mathrm{l}) = (3.3 \pm 1.0_{stat} \pm 1.66_{syst\, b\to c} \pm 0.55_{syst\, b\to u}) \times 10^{-3}$$

Background error	$\Delta\mathrm{Br}(\mathrm{b} \to \mathrm{X_u}\ell\nu)$
b-hadron production	$\pm 0.68 \times 10^{-3}$
b-hadron decay	$\pm 1.42 \times 10^{-3}$
detector effects	$\pm 0.52 \times 10^{-3}$
Signal error	**$\Delta\mathrm{Br}(\mathrm{b} \to \mathrm{X_u}\ell\nu))$**
MC statistics	$\pm 0.06 \times 10^{-3}$
Exclusive π rate	$\pm 0.19 \times 10^{-3}$
lepton spectrum (ISGW)	$\pm 0.04 \times 10^{-3}$
π spectrum	$\pm 0.27 \times 10^{-3}$
Λ_b rate	$\pm 0.43 \times 10^{-3}$

DELPHI analysis:
Inclusive Reconstruction of $\mathrm{b} \to \mathrm{X_u} \ell \nu$ Decays
(PRELIMINARY: First Presentation at the ICHEP-98 Conference, Vancouver B.C. (1998))

Analysis Technique

- ✦ Selection of b-tagged hadronic events with one identified e or μ;
- ✦ Inclusive reconstruction of secondary hadronic system and determination of secondary hadronic mass M_X and B decay mass $M_{X\ell\nu}$;
- ✦ Determination of the lepton energy in B rest frame E_ℓ^*;
- ✦ Definition of $b \to u$ enriched and depleted decay configurations by K identification and lepton i.p. and classification of decays into four classes:

$M_X < 1.6$ GeV/c^2 $b \to u$ enriched	$M_X < 1.6$ GeV/c^2 $b \to u$ depleted
$M_X > 1.6$ GeV/c^2 $b \to u$ enriched	$M_X > 1.6$ GeV/c^2 $b \to u$ depleted

- ✦ Extraction of BR$(b \to X_u \ell \nu)$ from a likelihood fit to the number of selected events and the shape of the E_ℓ^* distribution.

Inclusive Decay Reconstruction

✦ Selection of b-tagged hadronic events with one identified e or μ with $p > 3.0$ GeV/c and $p_t > 0.5$ GeV/c,

✦ INCLUSIVE RECONSTRUCTION OF SECONDARY HADRONIC SYSTEM:

B DECAY PRODUCT PROBABILITIES

✦ Probability for a particle of being a B decay product:

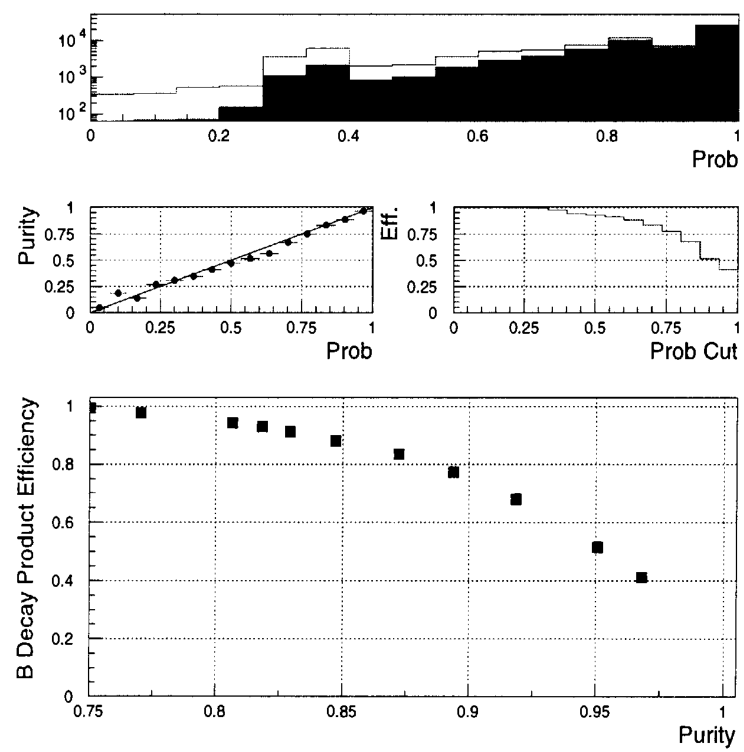
✦ $P_{sec} = \Pi_i f_i(x)$ where $f_i(x)$ are the fractions of secondary particles for the following variables:

★ All particles:

p_t, p/E_{jet}, mass, rapidity, particle momentum rank and $M_{sec\ vtx+part} - M_{sec\ vtx}$

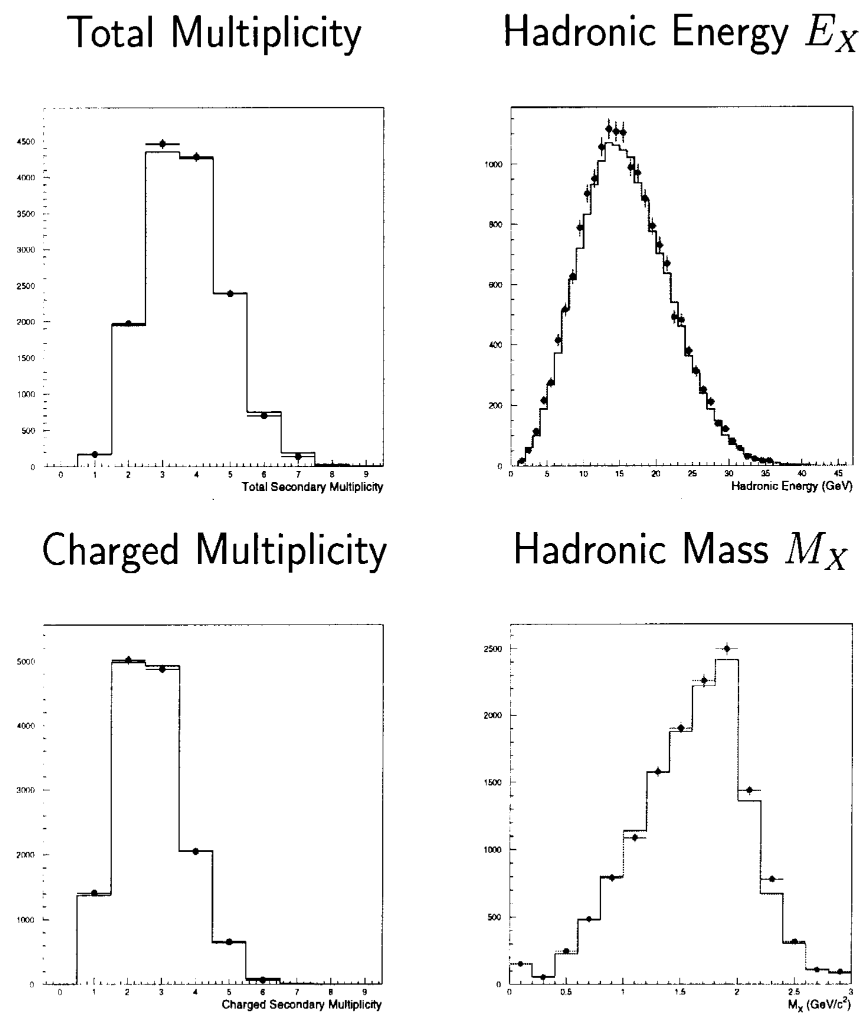
★ Charged particles:

i.p./$\sigma_{i.p.}$ in $R\phi$ and z projections, $\chi^2_{sec\ vtx+part} - \chi^2_{sec\ vtx}$ and L/D



INCLUSIVE SECONDARY VERTEX RECONSTRUCTION

✦ bundle charged particles with large values of P_{sec},
✦ iterative reconstruction of inclusive sec. vtx.,
✦ test addition of tagged K^0_s's and candidate secondary π^0's,
✦ determine invariant mass M_X and energy E_X of reconstructed secondary hadronic system.



PERFORMANCES IN $b \to c\ell\nu$ DECAYS:

✦ Average Charged Multiplicity $= 2.74 \pm 0.01$
✦ Average Total Multiplicity $= 3.64 \pm 0.01$

Selection Cuts

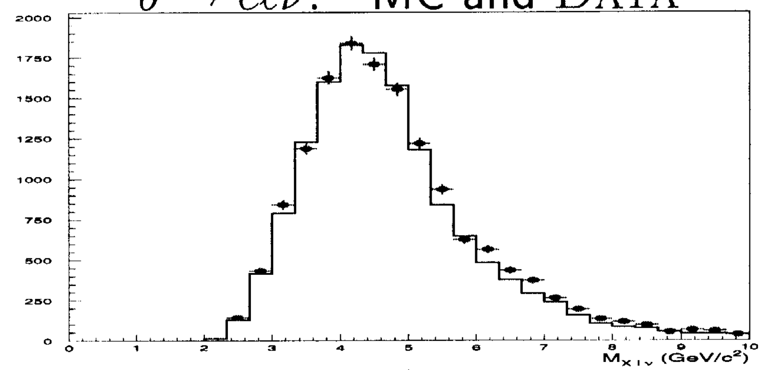
$E_B > 25$ GeV $E_X > 4$ GeV $-2 < Q_{vtx} < 2$
$E_{X\ell} > 12$ GeV $M_{X\ell} > 2$ GeV/c^2 $Q_{vtx} + Q_\ell < 2$
$d_{\ell\pi}/\sigma_d > 1.5$

B Decay Mass $M_{X\ell\nu}$

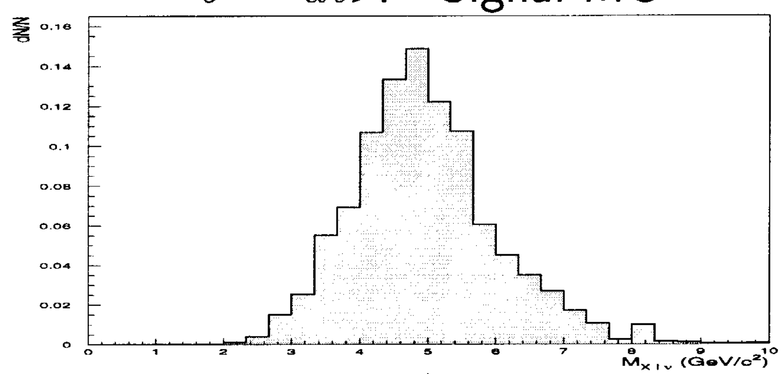
✦ Reconstruct ν direction and energy from p_{miss},

✦ determine invariant mass of B decay $M_{X\ell\nu}$

$b \to c\ell\nu$: MC and Data



$b \to u\ell\nu$: Signal MC



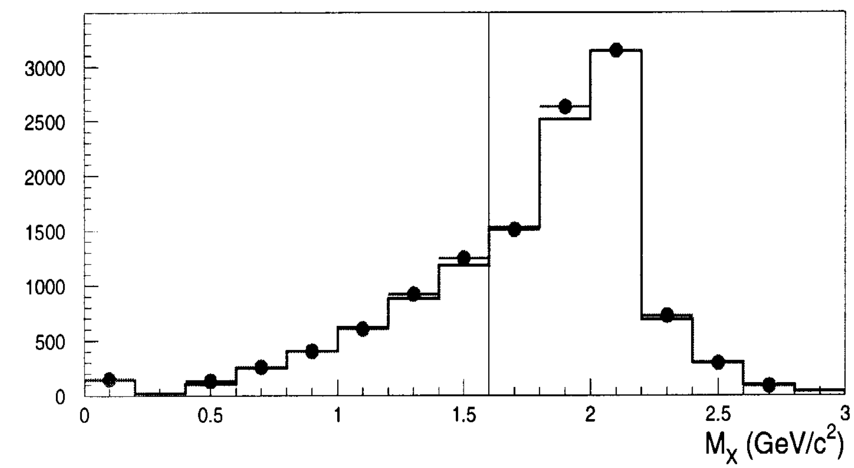
Secondary Hadronic Mass M_X

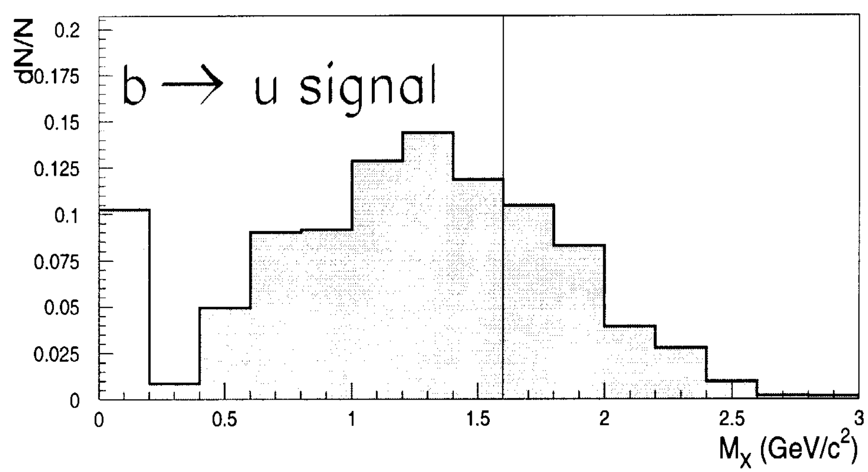
- Test compatibility of $M_{X\ell\nu}$ with M_B to identify partially reconstructed decays,

- scale M_X by $M_{X\ell\nu}/M_B$,

reconstruct D^* decay candidates inclusively and set $M_X = M_{D^*}$.

$b \to c\ell\nu$: MC and Data





Lepton Energy in B Rest Frame E_ℓ^*

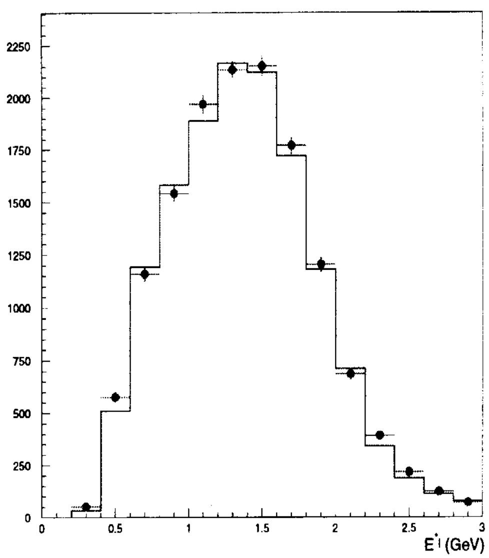
✦ Estimate B energy and direction from the hadronic system $+ \ell + p_{miss}$,

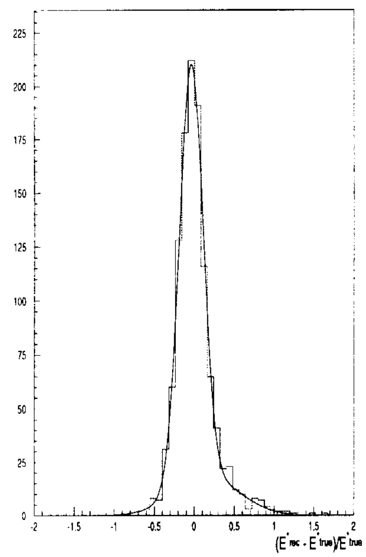
B Energy resolution $\Delta E_B / E_B = 10\%$

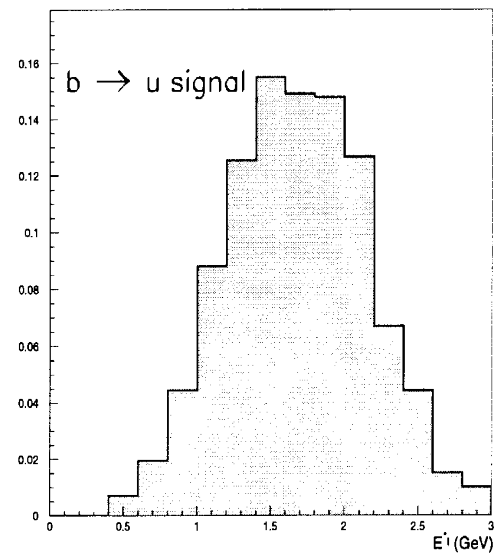
B Direction resolution $\simeq 3.5°$

E_ℓ^* resolution $= \Delta_{E^*}/E^* = 14\%$ for 81% of semileptonic decays:

E_ℓ^* MC and Data — E_ℓ^* Resolution — $b \to X_u \ell \nu$ Signal





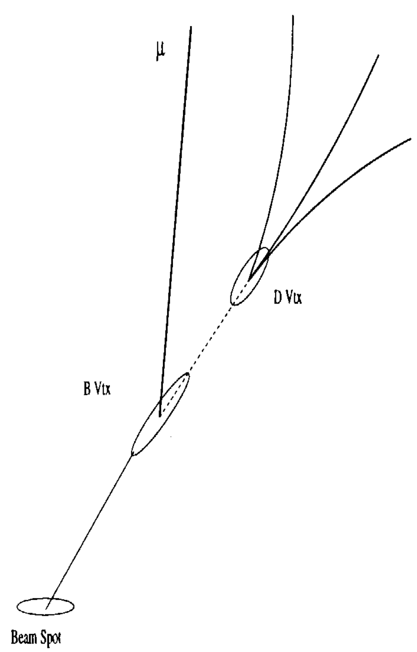


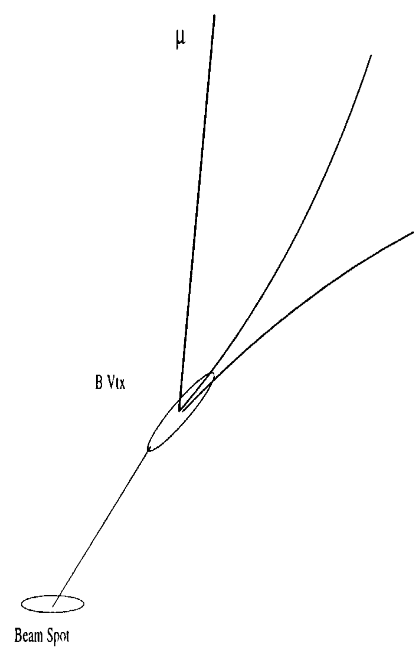
$b \to u\ell\nu$ Enrichment

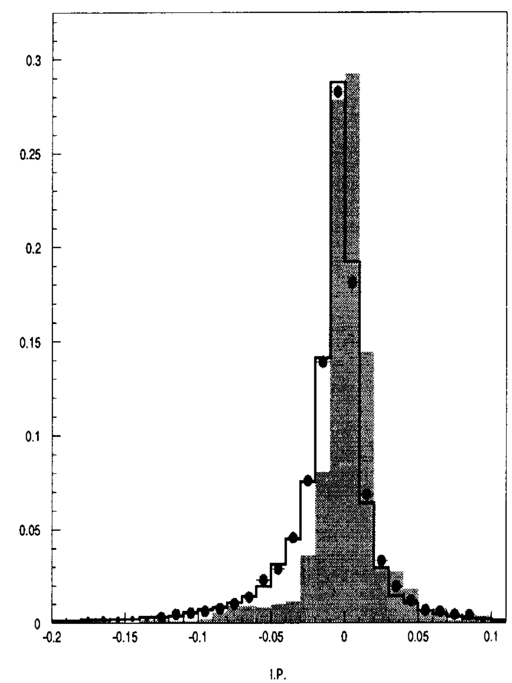
i) Tag kaons from $b \to c$, $c \to s$

ii) Compute ℓ impact parameter w.r.t. hadronic secondary vertex and sign using lifetime convention:

	$b \to c\ell\nu$	$b \to u\ell\nu$
i.p.:	– Sign and c lifetime	$\pm$ Sign





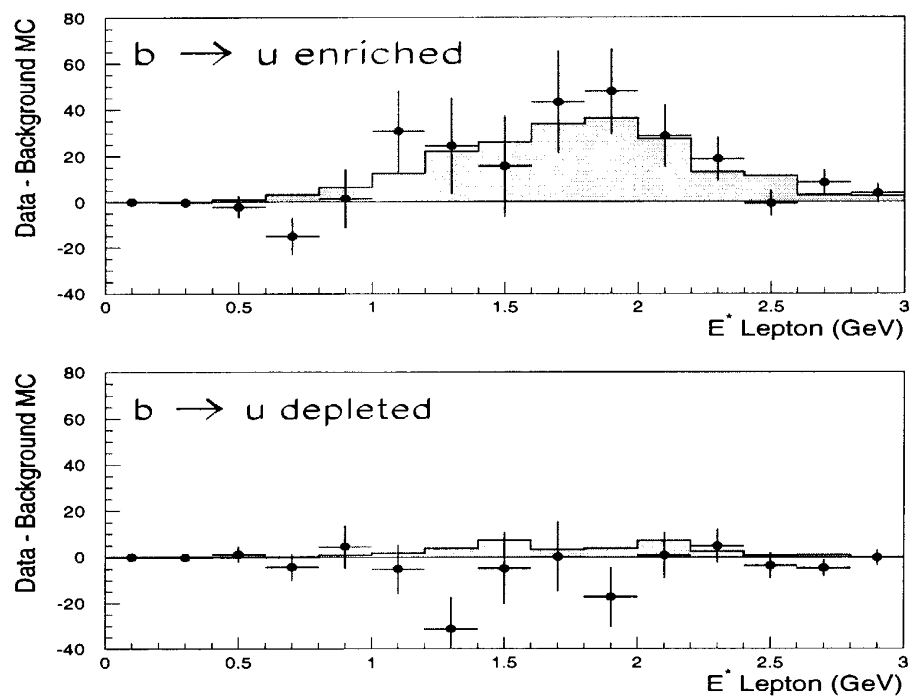


Preliminary DELPHI Result

DATA / MC BKG / FRACTION OF $b \to u\ell\nu$ SIGNAL

	$b \to u$ enriched	$b \to u$ depleted
$M_X < 1.6$	2292±48 / 2087±30 / 68%	1081±33 / 1143±19 / 9%
$M_X > 1.6$	5017±71 / 4901±58 / 17%	3744±61 / 3648±45 / 6%

BACKGROUND SUBTRACTED E_ℓ^* DISTRIBUTIONS $M_X < 1.6$ GeV/c^2

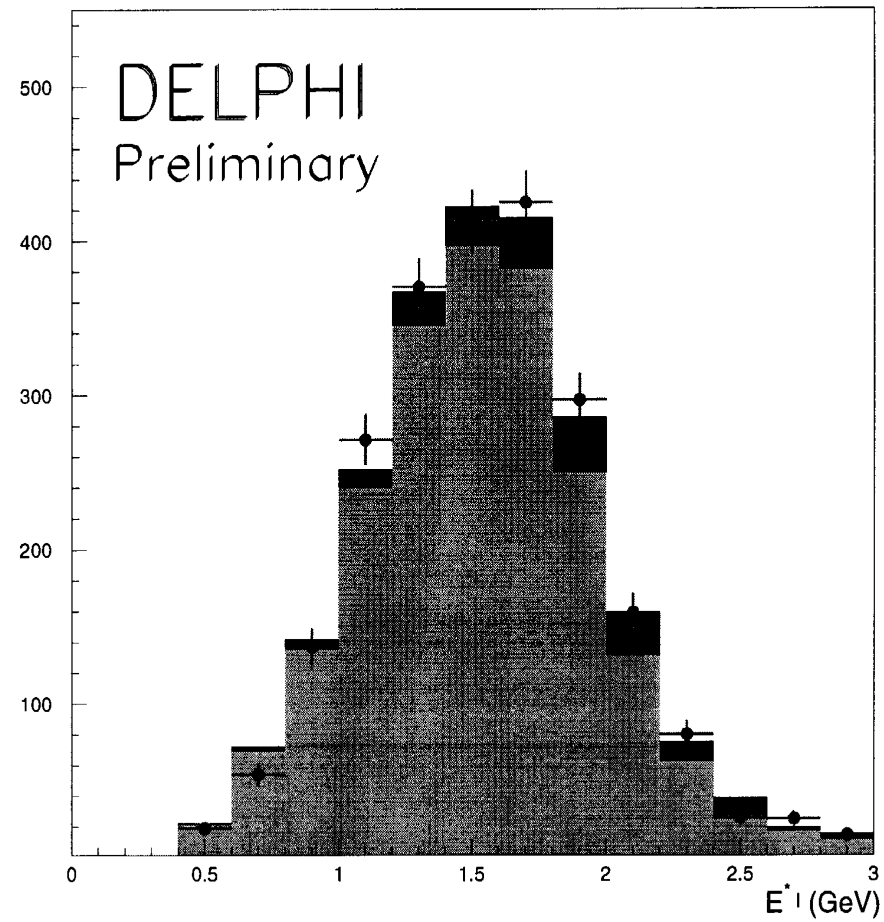


DELPHI BR($b \to X_u \ell \nu$) Fit

Excess of 205 $\pm$ 57 Data Events in low M_X signal enriched class,

Fit fraction of $b \to X_u \ell \nu$ decays and Data/MC Normalisation by binned maximum likelihood fit to number of selected events and E^*_ℓ distribution,

Extract BR($b \to X_u \ell \nu$) for $|V_{cb}| = 0.0395 \pm 0.0017$.



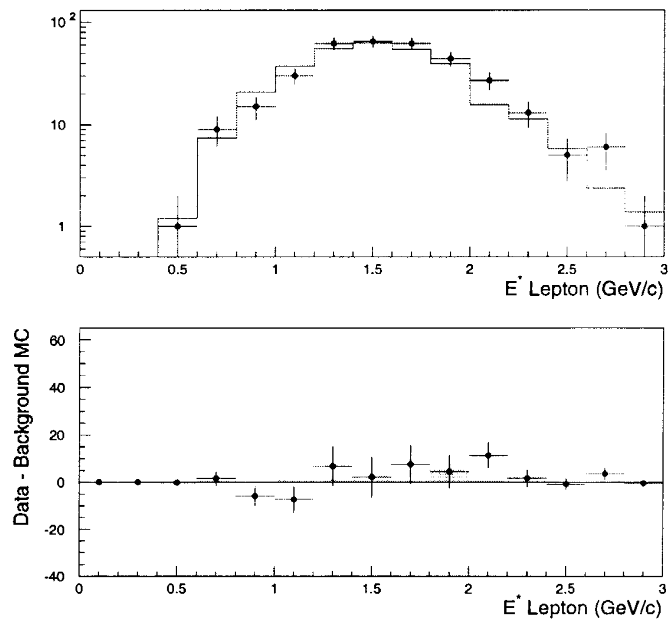
$$\mathrm{BR}(b \to X_u \ell \nu) = (1.53 \pm 0.37\ (\mathrm{stat.})) \times 10^{-3}$$

DELPHI Consistency Checks

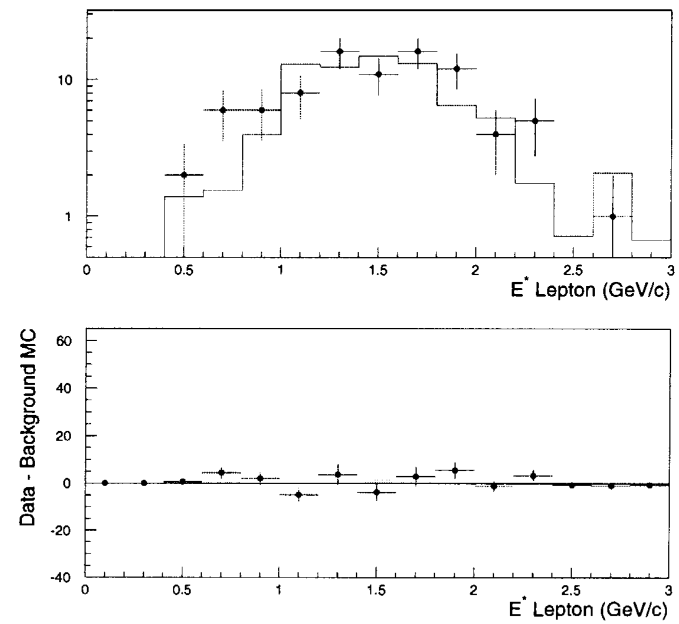
Cut	BR($b \to X_u \ell \nu$) ($\times 10^3$)
Std	1.53 ± 0.37
$M_X < 1.25$	1.49 ± 0.39
$M_X < 1.75$	1.35 ± 0.50
$p_t > 0.25$	1.54 ± 0.39
$p_t > 0.80$	1.43 ± 0.45

b-tag < 0.01	1.44 ± 0.45
$d_{\ell\pi}/\sigma_d > 2.5$	1.46 ± 0.42
$M_{X\ell} > 0$	1.56 ± 0.33
$E_{X\ell} > 0$	1.50 ± 0.33
$E_B > 0$	1.51 ± 0.37
no M_X scaling	1.56 ± 0.39

Same Sign Lepton-Vtx



Anti b-tagged

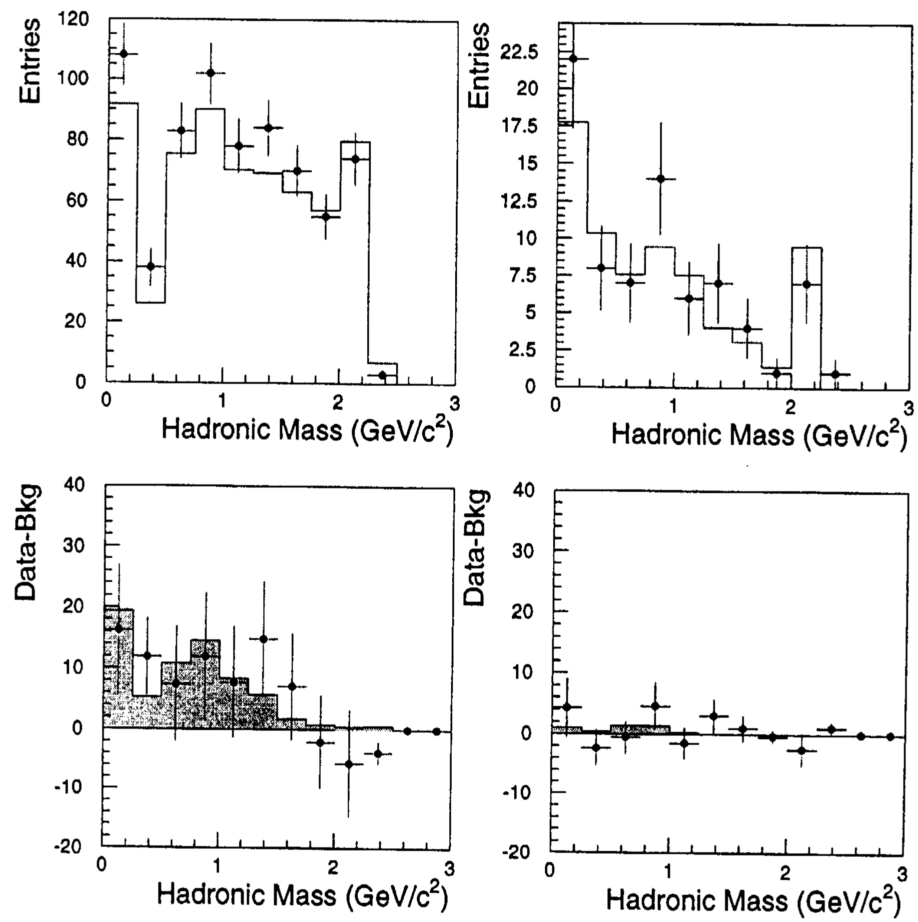


Selection of Exclusive Hadronic Final States

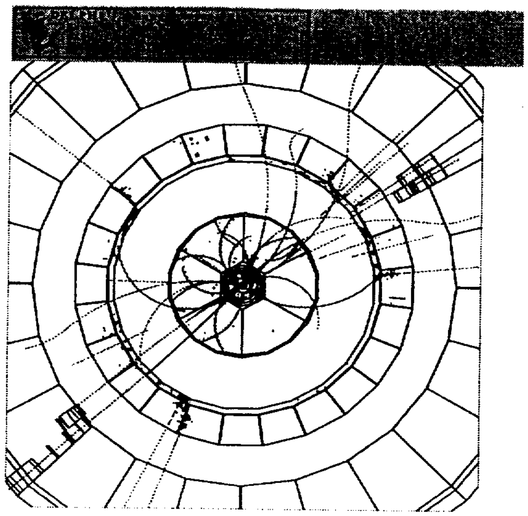
✦ Select one and two particle hadronic secondary systems with 1.0 GeV $< E_\ell^* < 3.0$ GeV and same selection criteria of the inclusive analysis

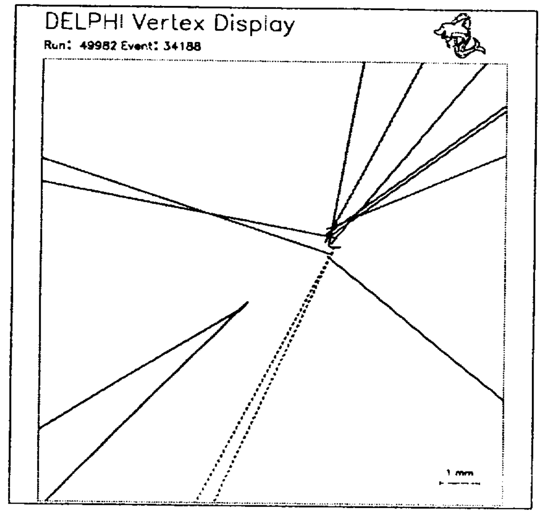
✦ Study invariant mass $M_X = M_\pi, M_{\pi^+\pi^-}, M_{\pi^\pm\pi^0}$ distribution of selected candidates

Right Sign Vtx - ℓ Wrong Sign Vtx - ℓ

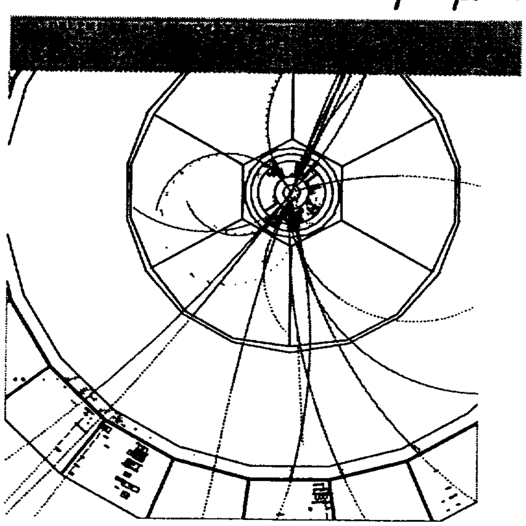


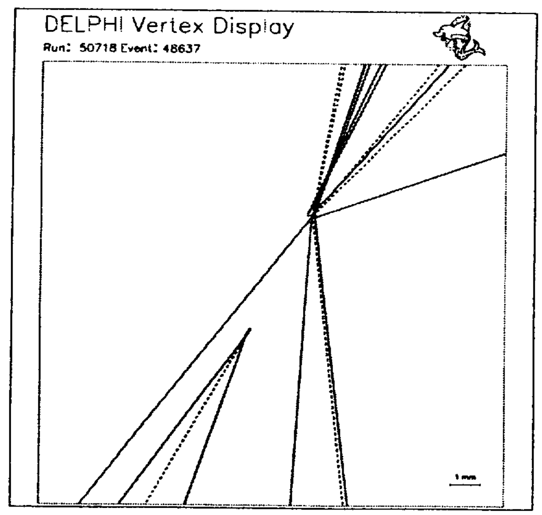
$$B^0 \to \pi^+ \mu^- \bar{\nu}$$





$$B^0 \to \rho^- \mu^+ \nu,\ \rho^- \to \pi^- \pi^0$$





Systematic Uncertainties

DELPHI Systematic Uncertainties on BR($b \to X_u \ell \nu$) (in units 10^{-3})

Source	Value ± Range	Syst. Error
e / μ id. Efficiency	$\pm 2.5\%$	0.04
e / μ id. Purity	$\pm 10\%$ / $\pm 4.5\%$	0.06
Hadronic Multiplicity		0.19
Neutral Energy Resolution		0.03
Missing Energy Resolution		0.03
ℓ Impact Parameter Sign		0.21
K id. Efficiency	$\pm 5\%$	0.05
Signal Efficiency	$\pm$ 2.4%	0.04
BR($D \to K^0 X$)	0.53 ± 0.05	0.18
BR($D \to 0, 1$ prong)	0.22 ± 0.02	0.06
$\frac{\mathrm{BR(b \to \ell)}}{\mathrm{BR(c \to \ell)}}$	$\frac{0.109 \pm 0.002}{0.094 \pm 0.010}$	0.18
$f(B_u) + f(B_d)$	0.834 ± 0.026	0.15
$< x_b >$	0.702 ± 0.008	0.03
b lifetime	1.566 ± 0.018	0.04
BR($b \to c\bar{c}s$)	0.15 ± 0.03	0.07
BR($B \to D^* \ell \nu + D^{**} \ell \nu$)	0.069 ± 0.015	0.17
$\frac{\mathrm{BR(B \to D^{(*)} \pi \ell \nu)}}{\mathrm{BR(B \to (D^{**} + D^{(*)} \pi) \ell \nu)}}$	0.25 $\pm$ 0.25	0.19
m_b	4.82 ± 0.10	0.14
$< p_b^2 >$	0.4 ± 0.1	0.04
b Kinematic Model		0.03
Hadronisation Model		0.17
Total		**0.57**

Preliminary DELPHI Result

DELPHI Systematic Uncertainties on BR($b \to X_u \ell \nu$) (in units 10^{-3})

Source	Value ± Range	Syst. Error
Detector Related		0.29
c Decays		0.26
b Decays		0.40
$b \to X_u \ell \nu$ Model		
m_b	4.82 ± 0.10	0.14
$< p_b^2 >$	0.4 ± 0.1	0.04
b Kinematic Model		0.03
Hadronisation Model		0.17
Total		**0.57**

$$\begin{aligned} \mathrm{BR}(\mathrm{b} \to \mathrm{X_u} \ell \nu) = (1.53\ & \pm 0.47\ (\mathrm{stat.} + \mathrm{det.}) \\ & \pm 0.44\ (b \to c) \\ (Preliminary) \quad & \pm 0.22\ (b \to u)) \times 10^{-3} \end{aligned}$$

The LEP BR($b \to X_u \ell \nu$) Average

The LEP $|V_{ub}|$ Working Group

SUMMARY OF BR($b \to X_u \ell \nu$) RESULTS AT LEP

Exp.	BR($b \to u\ell\nu$)	(stat.)	(det.)	(uncorr.)	(corr.)	
ALEPH	(1.73	$\pm$ 0.48	$\pm$ 0.29	$\pm$ 0.29	$\pm$ 0.47)	$\times 10^{-3}$
DELPHI	(1.53	$\pm$ 0.37	$\pm$ 0.28	$\pm$ 0.33	$\pm$ 0.36)	$\times 10^{-3}$
L3	(3.30	$\pm$ 1.00	$\pm$ 0.80	$\pm$ 0.68	$\pm$ 1.40)	$\times 10^{-3}$

Average ALEPH, DELPHI and L3 results using
the Best Linear Unbiased Estimate (B.L.U.E.) technique:

Unbiased estimate $\mathrm{BR_{LEP}}$ as linear combination of the different measurements $\mathrm{BR_i}$ at LEP...

$$\mathrm{BR_{LEP}} = \frac{\sum_{i=1}^{3}\sum_{j=1}^{3} \mathrm{BR_i}(\mathbf{E}^{-1})_{ij}}{\sum_{i=1}^{3}\sum_{j=1}^{3}(\mathbf{E}^{-1})_{ij}}$$

...corresponding to the minimum possible variance σ^2:

$$\sigma^2 = \frac{1}{\sum_{i=1}^{3}\sum_{j=1}^{3}(\mathbf{E}^{-1})_{ij}}$$

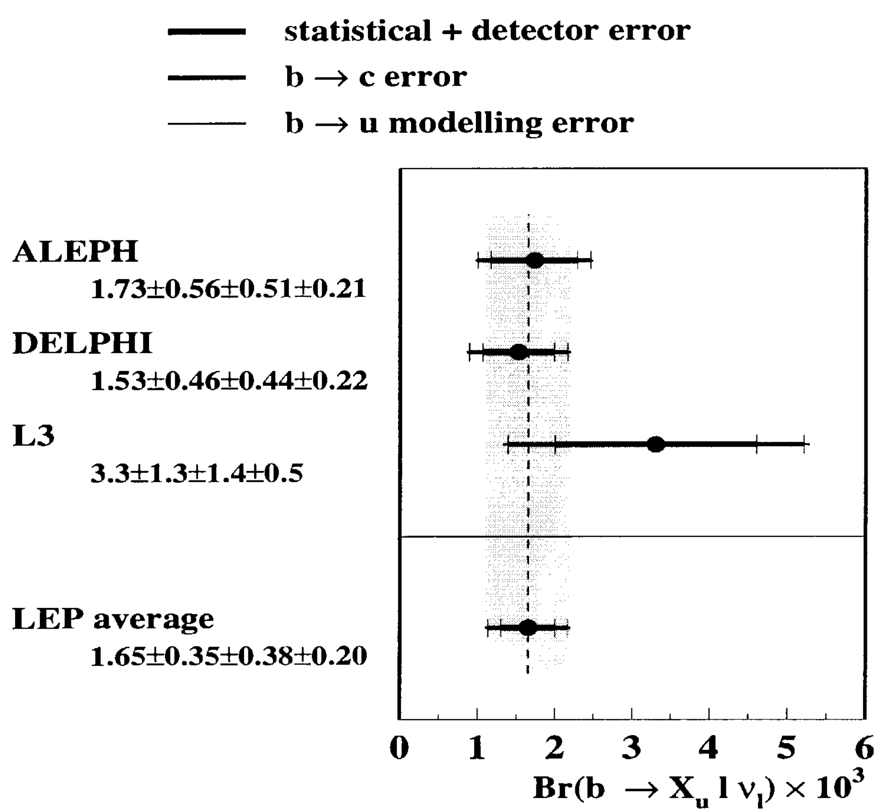
Correlated systematics from:

✦ $b \to c\ell\nu$ decay model ✦ c decay model ✦ $b \to u\ell\nu$ decay model

The LEP BR($b \to X_u \ell \nu$) Average

$$\mathrm{BR}(\mathrm{b} \to \mathrm{X_u}\ell\nu) = (1.65 \pm 0.35\ (\mathrm{stat.} + \mathrm{det.}) \pm 0.38\ (b \to c) \pm 0.20\ (b \to u)) \times 10^{-3}$$

$(Preliminary)$



THEORETICAL BASIS FOR THE EXTRACTION OF $|V_{ub}|$
(I. Bigi *et al.*)

- Good theoretical control established over $\Gamma(B \to X_u \ell \nu)$:

$$\Gamma(B \to X_u \ell \nu) = \frac{G_F^2 m_b^5(\mu_{NP})}{192\ \pi^3} |V_{ub}|^2 (1 + \frac{\Lambda}{m_b^2} + c_1 \frac{\alpha_s(\mu)}{\pi} + c_2 \frac{\alpha_s^2(\mu)}{\pi^2} + \ldots)$$

- non perturbative corrections $\simeq O(1/m_b^2)$ known,
- understand and know b-quark mass $m_b(\mu_{NP})$,
- know remaining perturbative corrections through $O(\alpha_s^2/\pi^2)$,

- **An accurate measurement of $\Gamma(B \to X_u \ell \nu)$ establishes a new standard for $|V_{ub}|$.**

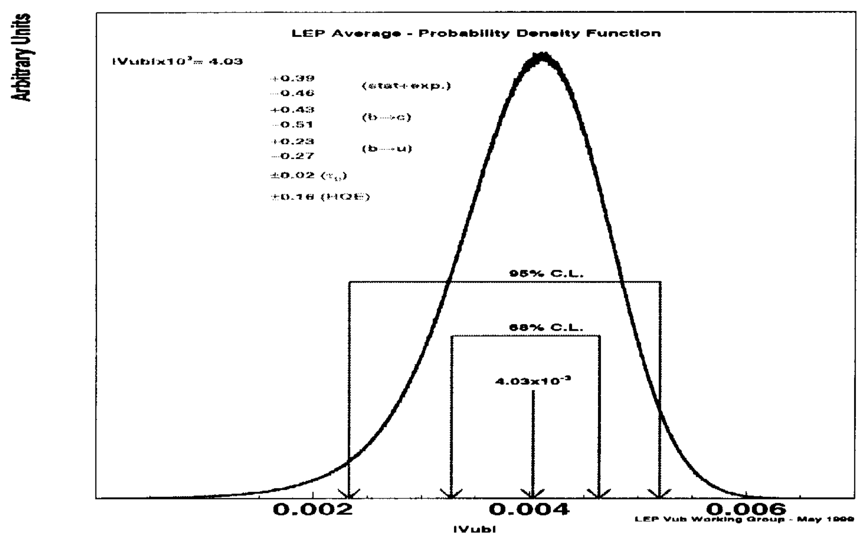
Preliminary Derivation of $|V_{ub}|$ at LEP

$|V_{ub}|$ value extracted using Heavy Quark Expansion:
(N. Uraltsev *et al*, Eur. Phys. J. **C4** (1998), 453

and A.H. Hoang *et al.*, Phys. Rev. Lett. **82** (1999), 277.)

$$|V_{ub}| = 0.00445 \times \left(\frac{\mathrm{BR}(b\to X_u \ell\nu)}{0.002}\,\frac{1.55\mathrm{ps}}{\tau_b}\right)^{\frac{1}{2}} \times (1 \pm 0.020(\mathrm{pert.}) \pm 0.035(\mathrm{m_b}))$$

(N. Uraltsev, hep-ph/9905520)



$$|V_{ub}| = (4.03 \ {}^{+0.62}_{-0.74}) \times 10^{-3} \text{ at } 68\% \text{ C.L.}$$
$$\phantom{|V_{ub}| = (4.03} \ {}^{+1.17}_{-1.70}) \times 10^{-3} \text{ at } 95\% \text{ C.L.}$$

Other $|V_{ub}|$ Determinations

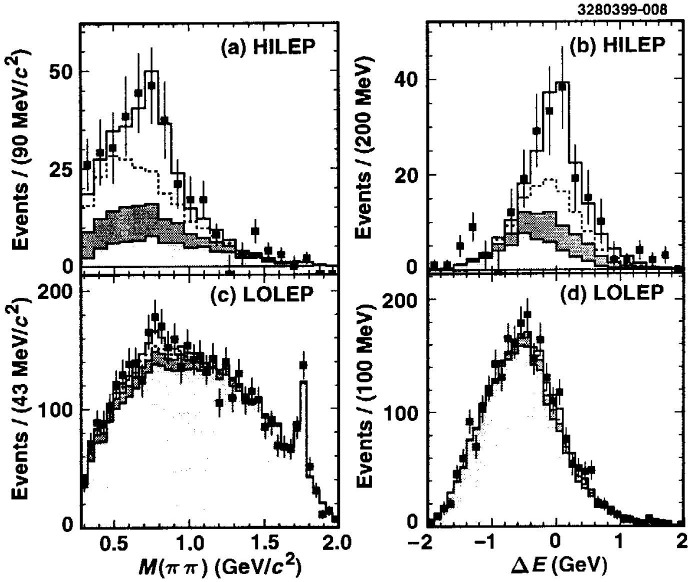
Determination from Lepton Spectrum End-point

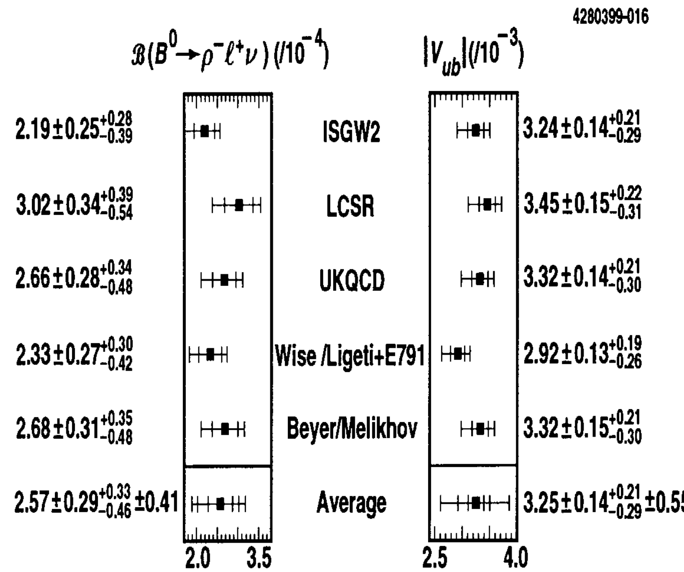
ARGUS + CLEO RESULT (PDG, 1998)

$$|V_{ub}| = (3.16 \pm 0.40\ (\text{stat.+syst.}) \pm 0.71\ (\text{model}) \pm 0.14\ (|V_{cb}|)) \times 10^{-3}$$

Determination from Exclusive $B_d^0 \to \rho^- \ell^+ \nu$ Decays

CLEO UPDATED RESULT (CLEO 99-3 May 24, 1999)





$$|V_{ub}| = (3.25 \pm 0.14\ (\text{stat.})\ ^{+0.21}_{-0.29}\ (\text{syst.}) \pm 0.55\ (\text{model})\ ) \times 10^{-3}$$

Conclusions

- Branching ratio for inclusive charmless semi-leptonic b decays BR($b \to X_u \ell \nu$) measured by ALEPH, DELPHI and L3 at LEP.
- Analysis techniques discriminate $b \to X_u \ell \nu$ from $b \to X_c \ell \nu$ transitions inclusively from the difference in invariant mass, multiplicity, vertex topology and hadron content of secondary hadronic systems X_u and X_c.

LEP average BR($b \to X_u \ell \nu$) value:

$$\begin{array}{ll} \mathrm{BR}(\mathrm{b} \to \mathrm{X_u}\ell\nu) = (1.65 & \pm 0.35\ (\mathrm{stat.} + \mathrm{det.}) \pm 0.38\ (b \to c) \\ \quad (Preliminary) & \pm 0.20\ (b \to u)) \times 10^{-3} \end{array}$$

$|V_{ub}|$ value derived using HQE:

$$\begin{array}{l} |V_{ub}| = (4.03\ {}^{+0.62}_{-0.74}) \times 10^{-3} \text{ at } 68\% \text{ C.L.} \\ \qquad\qquad\quad {}^{+1.17}_{-1.70}) \times 10^{-3} \text{ at } 95\% \text{ C.L.} \end{array}$$

- Inclusive analysis of $b \to X_u \ell \nu$ transitions at LEP provided a determination of the $|V_{ub}|$ element with small model uncertainty.